IBM Compilers for pSeries

SCICOMP

IBM SP Scientific Computing User Group

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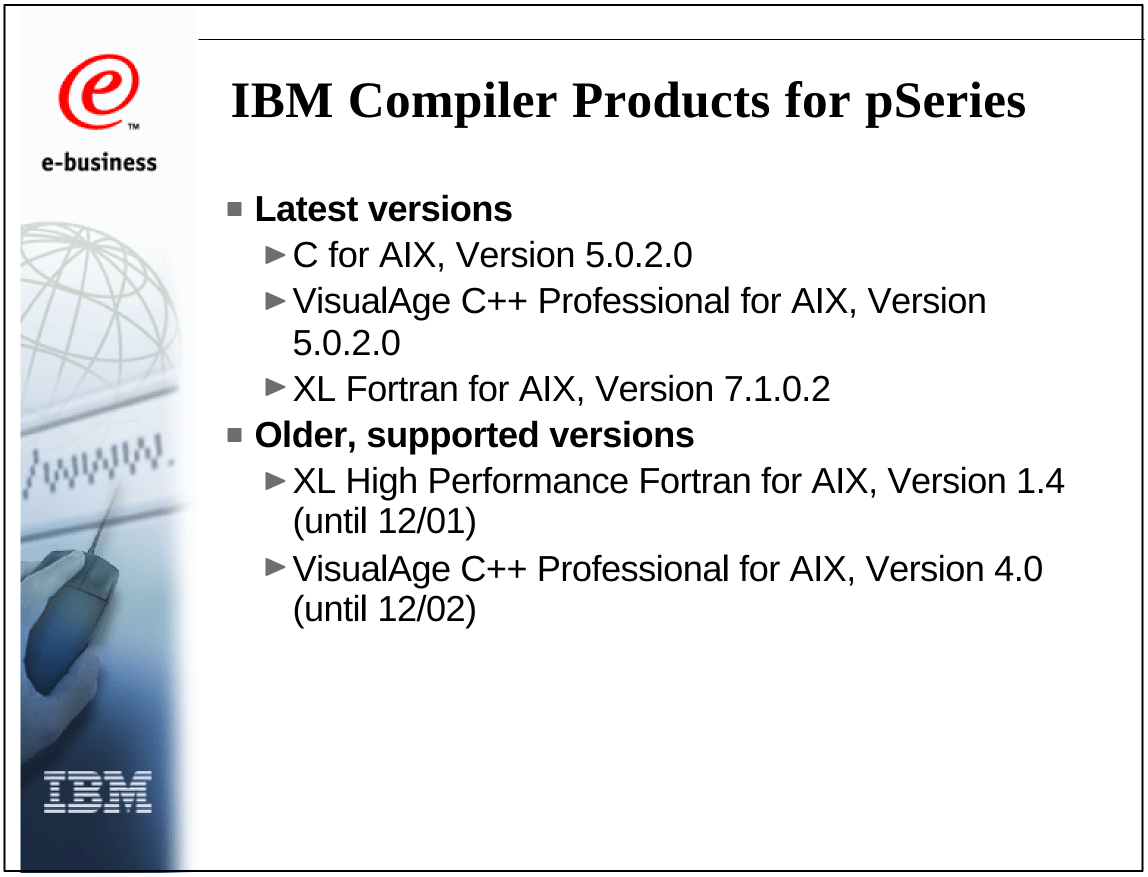
Bob Blainey
blainey@ca.ibm.com

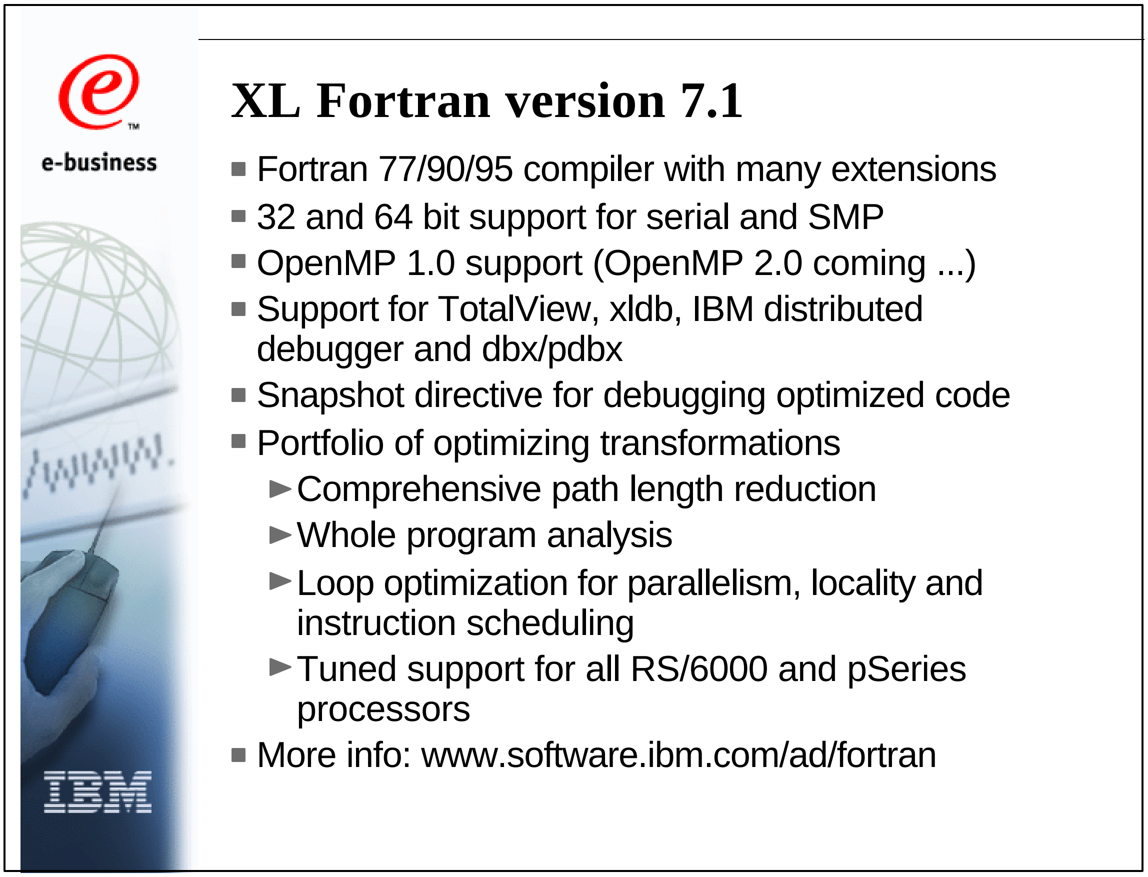
Agenda

- Review of the pSeries compiler products
- Compiler Configuration Options
- Compiler roadmap
- Some Performance Results
- A short tutorial on performance controls
- A peek inside the compiler
- Q&A



IBM Compiler Products for pSeries

- **Latest versions**
  - C for AIX, Version 5.0.2.0
  - VisualAge C++ Professional for AIX, Version 5.0.2.0
  - XL Fortran for AIX, Version 7.1.0.2
- **Older, supported versions**
  - XL High Performance Fortran for AIX, Version 1.4 (until 12/01)
  - VisualAge C++ Professional for AIX, Version 4.0 (until 12/02)



XL Fortran version 7.1

- Fortran 77/90/95 compiler with many extensions
- 32 and 64 bit support for serial and SMP
- OpenMP 1.0 support (OpenMP 2.0 coming ...)
- Support for TotalView, xldb, IBM distributed debugger and dbx/pdbx
- Snapshot directive for debugging optimized code
- Portfolio of optimizing transformations
  - Comprehensive path length reduction
  - Whole program analysis
  - Loop optimization for parallelism, locality and instruction scheduling
  - Tuned support for all RS/6000 and pSeries processors
- More info: www.software.ibm.com/ad/fortran

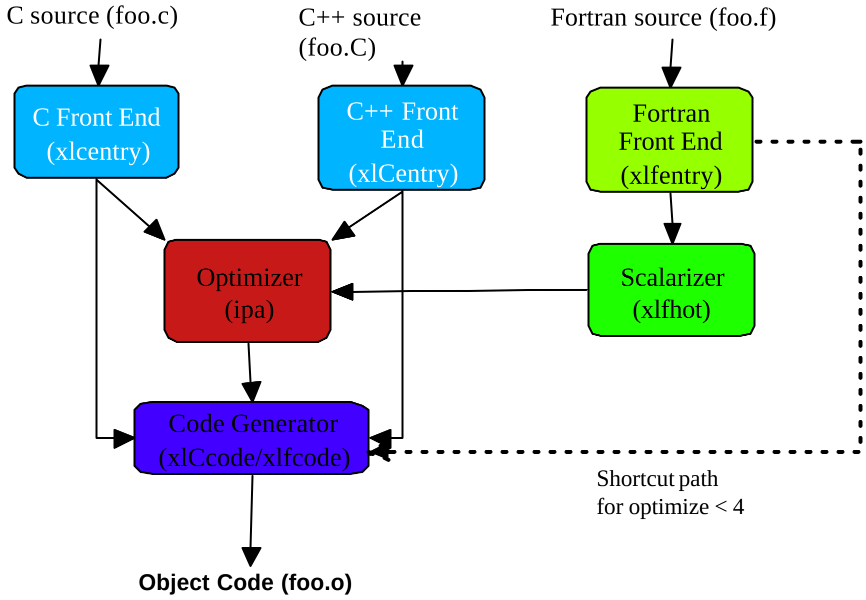
C for AIX version 5.0

- ANSI C89 compliant compiler (C99 coming soon)
- 32 and 64 bit support for serial and SMP
- Full support for OpenMP 1.0 (participating in OpenMP 2.0 definition)
- Support for TotalView, xldb, IBM distributed debugger and dbx/pdbx
- Snapshot directive for debugging optimized code
- Runtime memory debug support
- Portfolio of optimizing transformations
  - Similar to Fortran support but includes tuned optimizations for C pointers and systems coding styles
- More info: www.software.ibm.com/ad/caix

VisualAge for C++ for AIX version 5.0

- Fully compliant ANSI98 C++ compiler
- 32 and 64 bit support
- Batch compiler for traditional build environments and maximal optimization
- Incremental compiler for rapid application development (to be phased out in next release)
- Integrated graphical development environment including remote debug and performance visualization
- Support for TotalView, xldb, IBM distributed debugger and dbx/pdbx
- Portfolio of optimizing transformations
  - Subset of transformations available in Fortran and C but has tuned support for all processors
  - Much more coming soon
- More info: www.software.ibm.com/ad/vacpp

Inside a Compilation Step



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Compiler Configuration Options

- **Configuration file (/etc/xlf.cfg, /etc/vac.cfg)**
  - Specifies default options and component and library paths for various compiler *invocations*
  - A compiler invocation (eg. xlf, xlf95, xlf_r) is simply a symbolic link to the compiler driver program (ie. argv[0]) used to obtain a specific behaviour - each has an associated stanza in the configuration file
  - You can specify your own configuration file using -F and you can create new stanzas ... take care if changing existing ones
- **-qpath option (old form uses -B and -t)**
  - Can be used to direct the compiler to use a component (eg. xlcentry, xlfcode) from a specific path
    - mixing components from different releases/PTFs works in general but is not warranted
    - recommend using a consistent set of components
  - Specifying a component other than the default one may require the use of a compatible runtime (ie. through the use of -L or LIBPATH) and a compatible message system (ie. through the use of NLSPATH)
- **TMPDIR**
  - Specifies an alternate directory for compiler temporary file storage - may be useful when using the -qipa option (including -O4, -O5)

Configuration Options: Multiple Concurrent Compiler Versions

- XL Fortran manual documents a procedure for installing a compiler release in an alternate location
- A similar technique can be used for C/C++
- A technique based on alternate configuration files can be used to create a mirror image of an installed compiler in a specified location.
- We understand that these procedures are poorly documented and difficult to understand and manage
- We will better document and support these types of concurrent installations in XL Fortran V8 and VAC/C++ V6 with these caveats:
  - PMRs would be accepted only for compilers installed through smit/installp
  - PTFs or efixes would not apply to compilers installed in alternate locations

XL Fortran Roadmap

- **XL Fortran 7.1.1 - GA 12/01**
  - Power 4 optimization
  - Improved F90 intrinsic performance (MATMUL, TRANSPOSE)
  - Improved SMP performance (Auto and OpenMP)
  - Improved compile performance
- **XL Fortran 8.1 - projected GA 2Q02**
  - OpenMP 2.0
  - Fortran 200x subset
    - IEEE intrinsic module
    - allocatable components
  - Even more Power 4 optimization
  - Whole program analysis for locality and auto SMP parallelism (-qipa + -qhot or -qsmp=auto)

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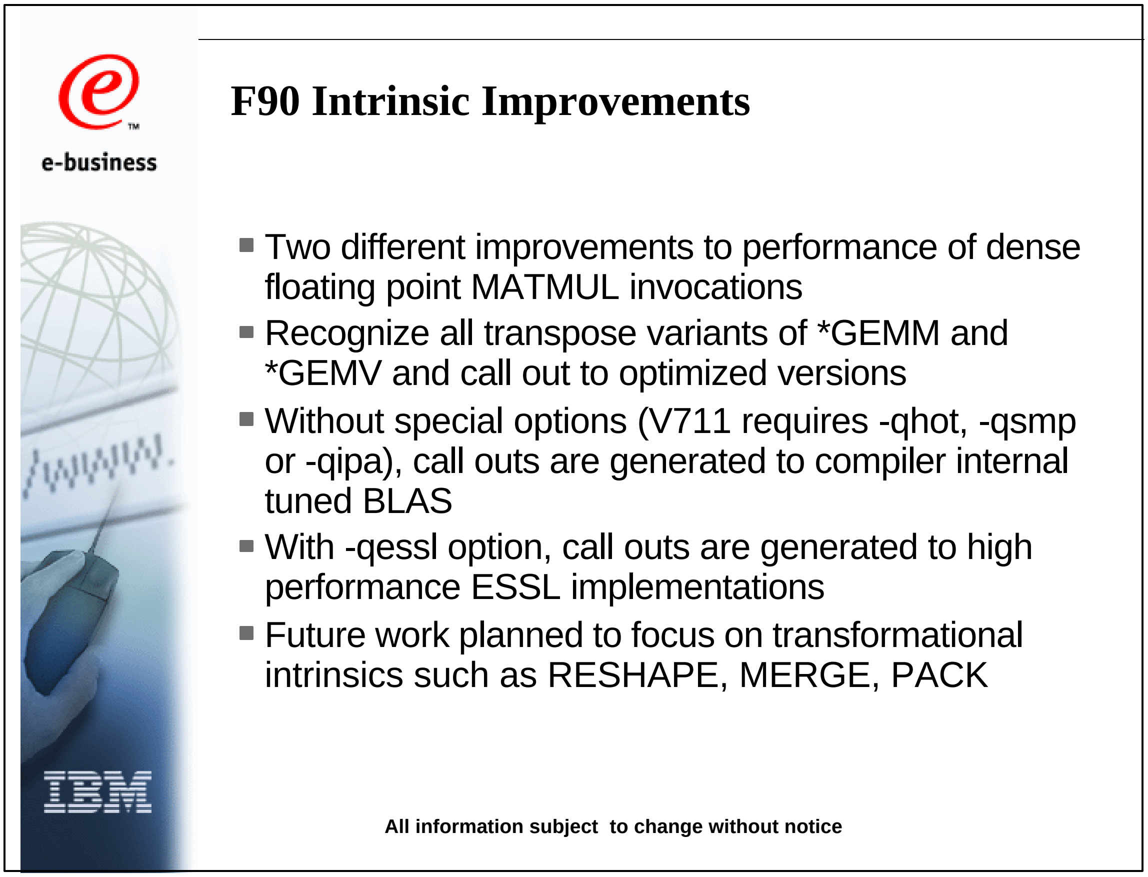

F90 Intrinsic Improvements

- Two different improvements to performance of dense floating point MATMUL invocations
- Recognize all transpose variants of *GEMM and *GEMV and call out to optimized versions
- Without special options (V711 requires -qhot, -qsmp or -qipa), call outs are generated to compiler internal tuned BLAS
- With -qessl option, call outs are generated to high performance ESSL implementations
- Future work planned to focus on transformational intrinsics such as RESHAPE, MERGE, PACK

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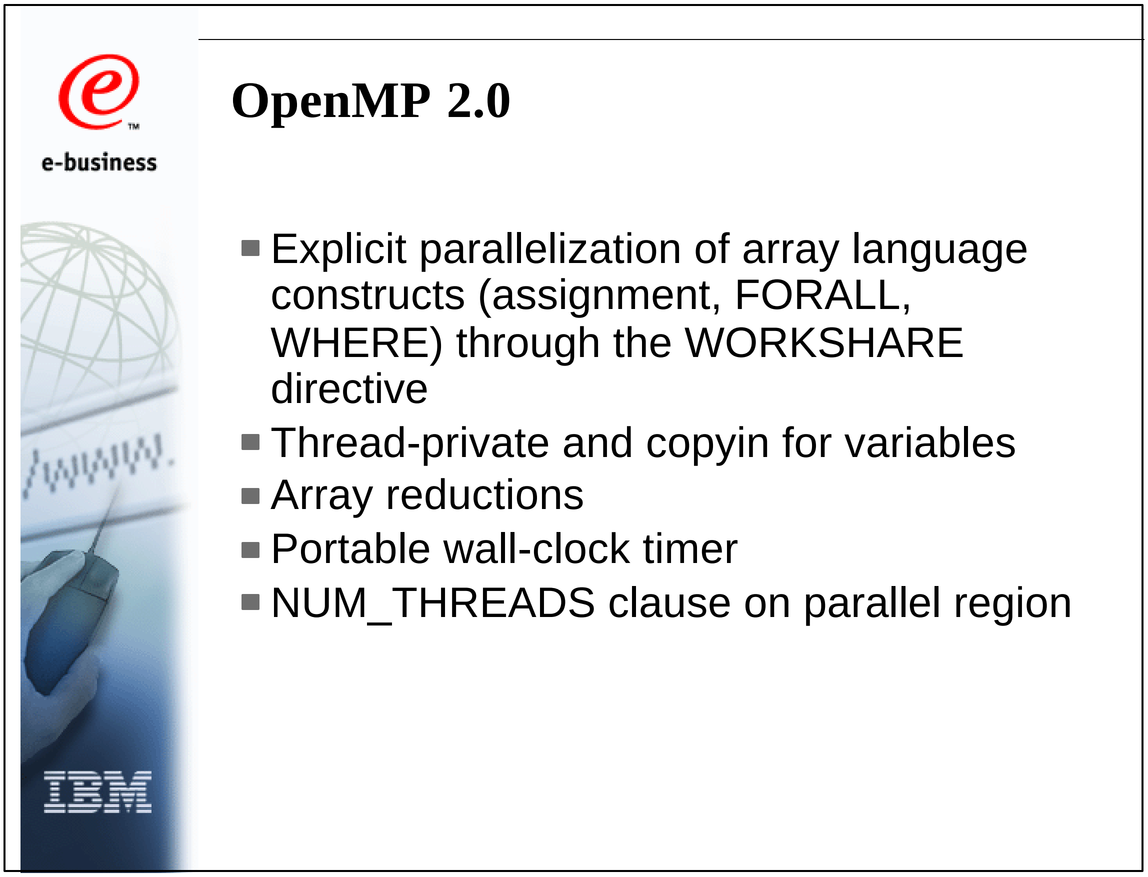

OpenMP 2.0

- Explicit parallelization of array language constructs (assignment, FORALL, WHERE) through the WORKSHARE directive
- Thread-private and copyin for variables
- Array reductions
- Portable wall-clock timer
- NUM_THREADS clause on parallel region

C for AIX Roadmap

- **C for AIX 6.0 beta - GA 12/01**
  - Power 4 optimization
  - Improved SMP performance (Auto and OpenMP)
  - Optimization of loops for locality (-qhot)
- **C for AIX 6.0 - projected GA 2Q02**
  - ANSI C99 support, notably:
    - _Bool and _Complex type specifiers
    - signed and unsigned long long
    - restricted pointers
    - inline functions
    - variable size automatic arrays
  - Many GNU C compatible language and preprocessor extensions
  - Even more Power 4 optimization
  - Whole program analysis for locality and auto SMP parallelism (-qipa + -qhot or -qsmp=auto)

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VisualAge for C++ for AIX Roadmap

- **VisualAge for C++ for AIX 6.0 beta - GA 12/01**
  - Power 4 optimization
  - Template code size optimizations
  - Optimization of virtual function calls
  - Improved optimization in the presence of exception handling
  - Whole program analysis (-qipa)
  - Optimization of loops for locality and auto SMP parallelism (-qhot, -qsmp=auto)
- **VisualAge for C++ for AIX 6.0 - projected GA 2Q02**
  - OpenMP 1.0 support (participating in OpenMP 2.0 definition)
  - Many GNU C/C++ compatible language and preprocessor extensions
  - Snapshot directive for debugging optimized code
  - Even more Power 4 optimization
  - Whole program analysis for locality and auto SMP parallelism (-qipa + -qhot or -qsmp=auto)

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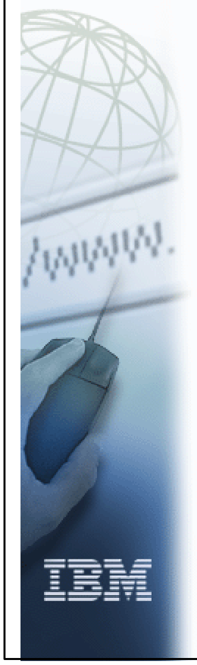

Common Optimization Technology Roadmap (Power 4 specific)

- **Architecture-neutral and -specific code paths**
  - ►tuning for arch=ppc and arch=pwr4
- **Precise machine model for scheduling (-O2+)**
  - ►new instruction scheduler with more detailed modelling capability
  - ►tuned through extensive experimention on early h/w
- **New loop transformations for deep pipelines (-O3+)**
  - ►more precise loop unrolling and pipelining
- **New aggressive branch optimizations (-O2+)**
  - ►branch pattern replacement
  - ►utilization of branch hints (eg. using profile feedback)
- **Optimized usage of hardware-expanded instructions**
  - ►eg. load/store update, mtcr, lm/stm
- **Optimized prefetch buffer allocation (-qhot)**
  - ►utilization of prefetch stream start instructions
  - ►loop nest fusion and partitioning to optimize # streams

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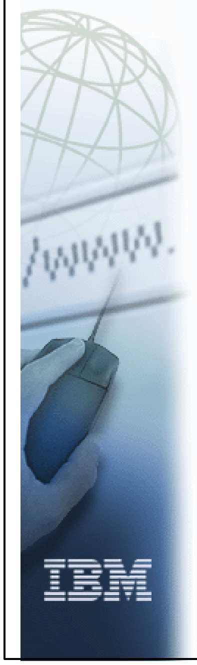

Common Optimization Technology Roadmap

- **Enhanced profile-directed optimization (-qpdf)**
  - ► Profile-directed inlining, specialization, code motion, loop optimization
  - ► Much faster instrumentation (-qpdf1) time (20-40% penalty vs. 2-5x)
- **Interprocedural optimization (-qipa)**
  - ► Improved link time and reduced memory requirements
  - ► Better handling of multiple levels of pointer indirection
  - ► Better handling of function pointer calls, virtual calls, C++ exceptions, templates
  - ► Much expanded database of known library behaviours (eg. pthreads, MPI, ESSL, MASS)

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Common Optimization Technology Roadmap *(continued)*

- **Loop optimization (-qhot, -qsmp=auto)**
  - ►Improved compile time
  - ►More precise data dependence analysis leading to new opportunities for nest fusion, partitioning, interchange, parallelization, vectorization, etc
  - ►More aggressive transformations including improved handling of triangular and imperfect nests, indirect array indexing and branching within loops
- **Whole program optimization for locality and auto SMP parallelism (-qipa + -qhot or -qsmp=auto)**
  - ►Better handling of loop nests with calls
  - ►Inlining and cloning tuned to loop optimization (eg. fusion)
  - ►Improved handling of partial array read/write (eg. column), even through reference parameters
    - Leads to coarser grain (ie. more profitable) automatic parallelism

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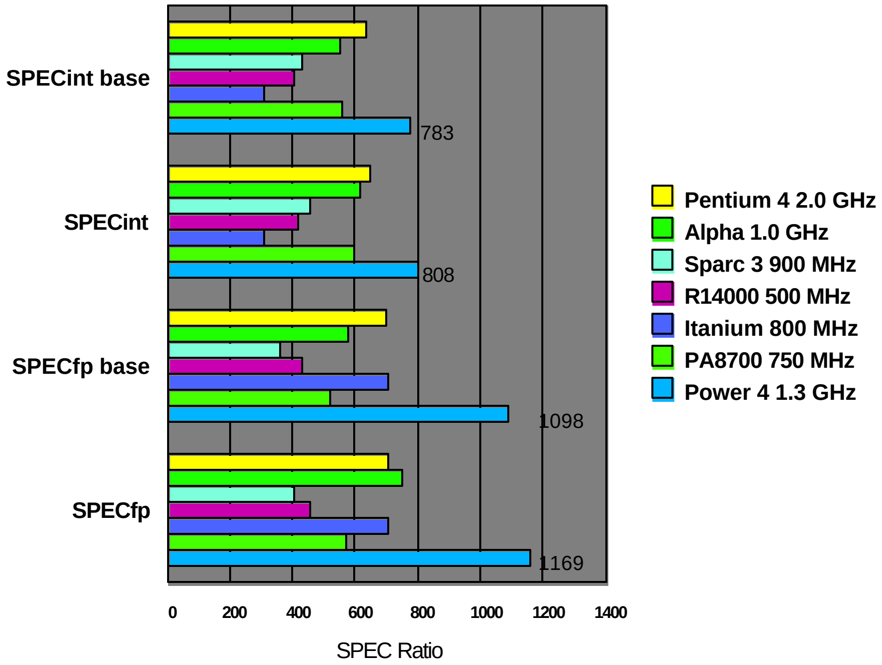
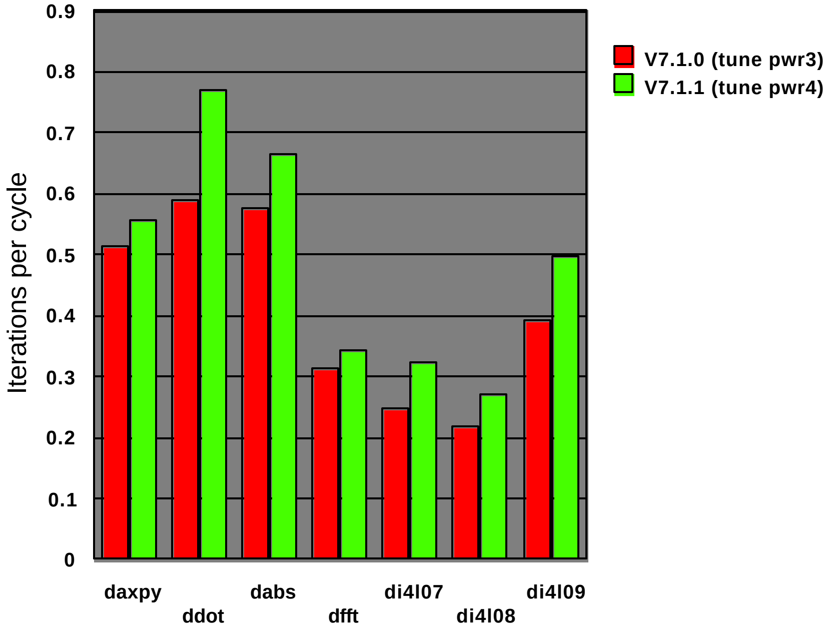
SPEC results for Power4

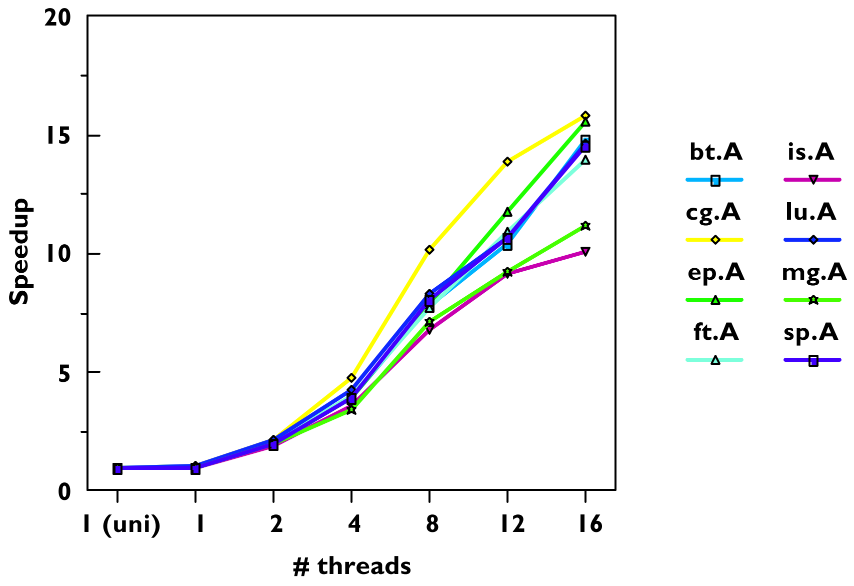


Competitive data from www.spec.org

Selected Kernel Performance



NAS OpenMP Speedup (16w NH-2)



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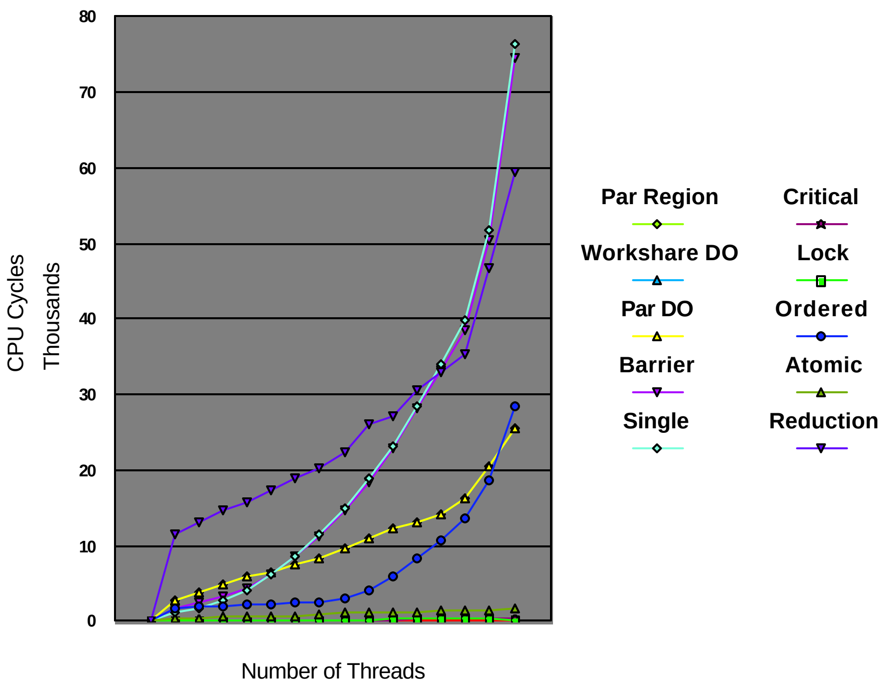
EPCC SyncBench Results - 16w NH-2



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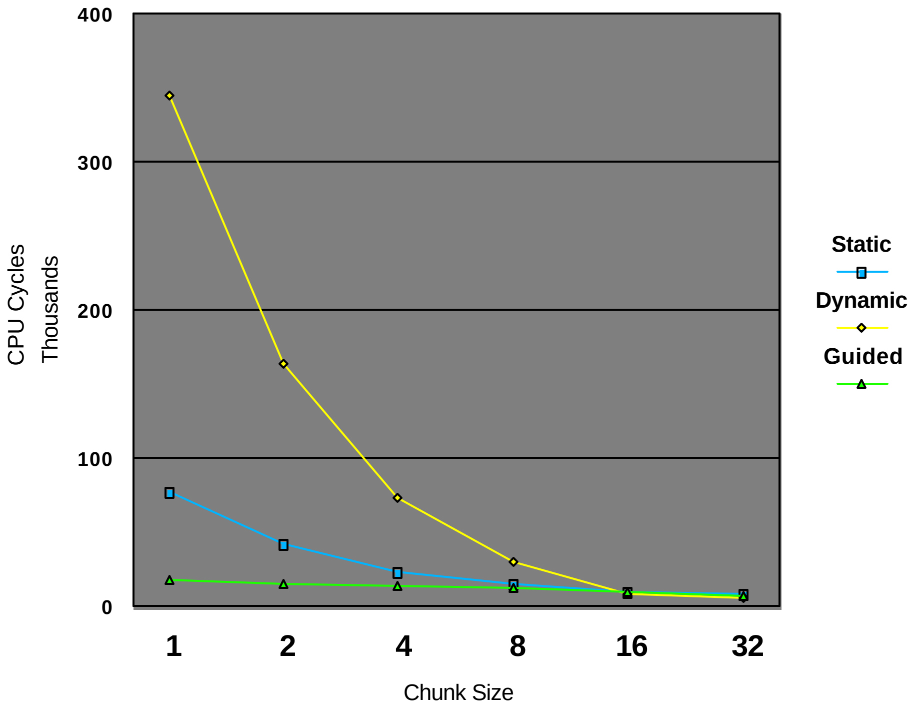
EPCC SchedBench Results - 16w NH-2



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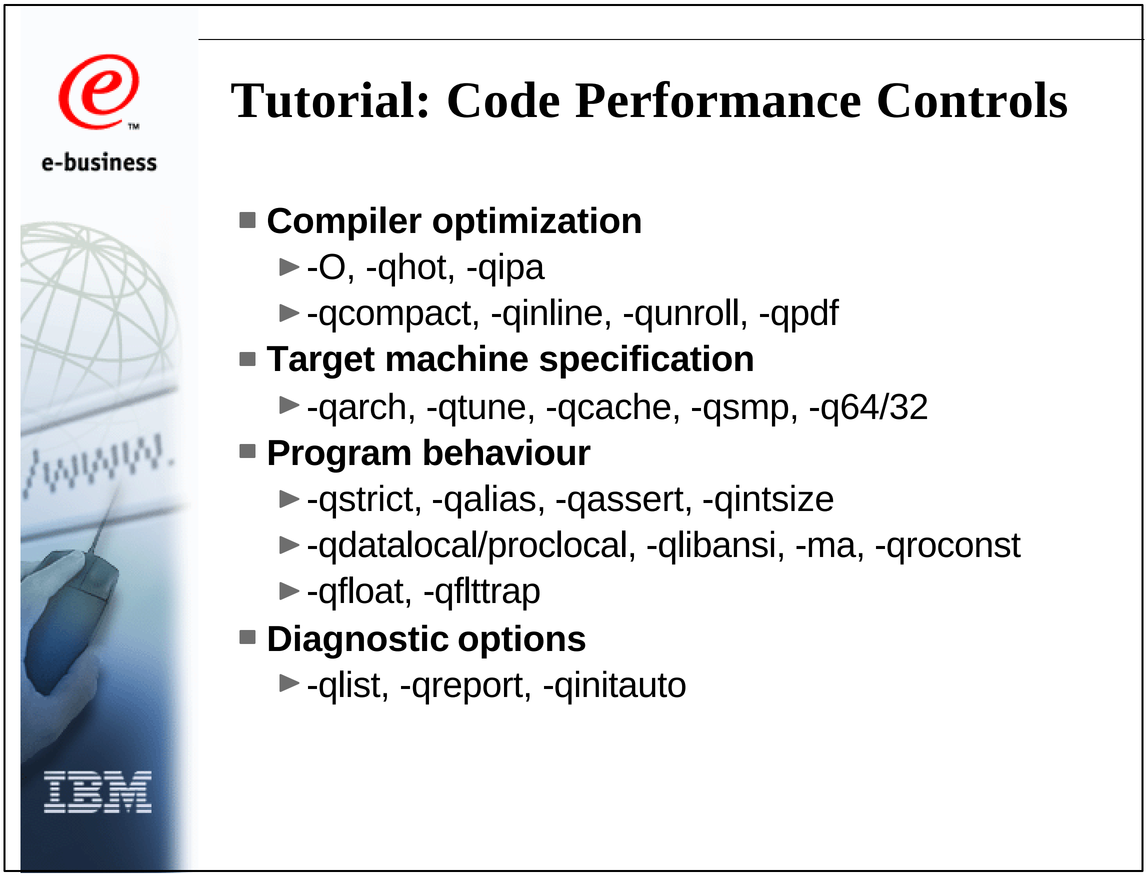
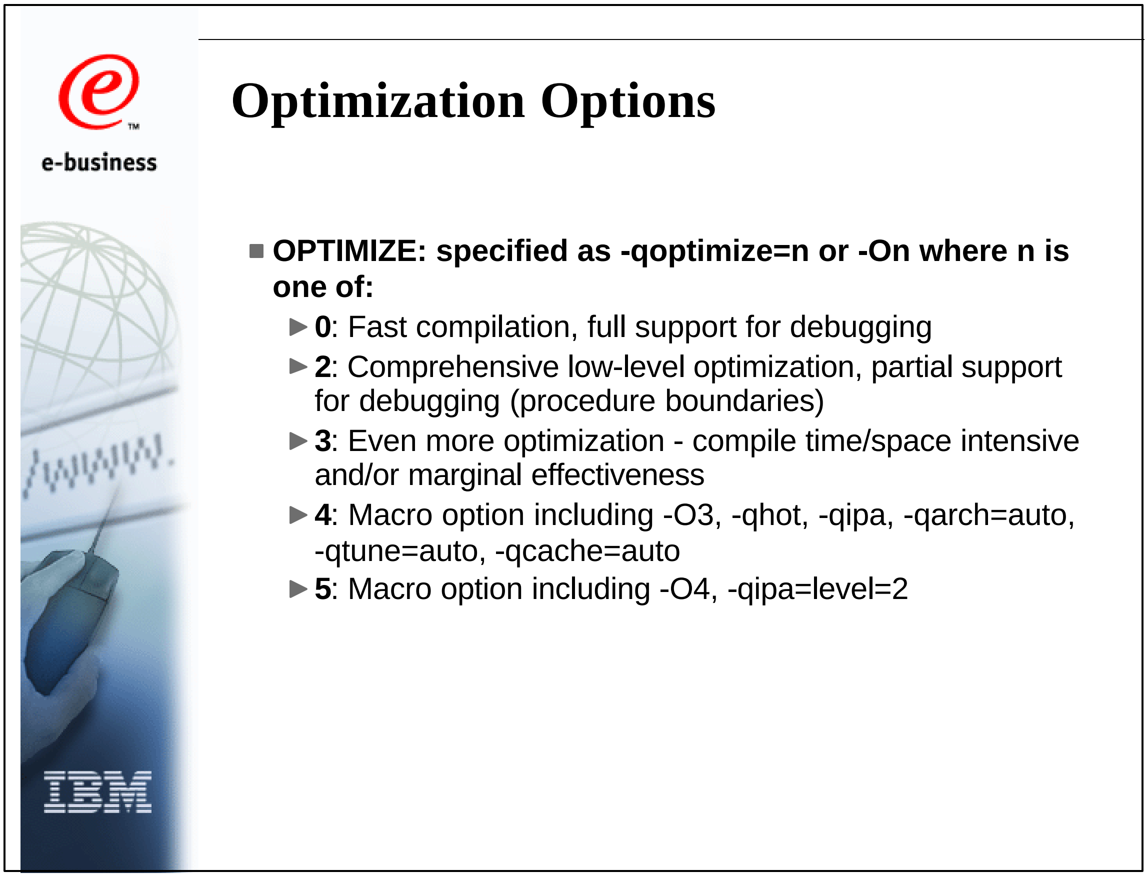


Tutorial: Code Performance Controls

- **Compiler optimization**
  - -O, -qhot, -qipa
  - -qcompact, -qinline, -qunroll, -qpdf
- **Target machine specification**
  - -qarch, -qtune, -qcache, -qsmp, -q64/32
- **Program behaviour**
  - -qstrict, -qalias, -qassert, -qintsize
  - -qdatalocal/proclocal, -qlibansi, -ma, -qroconst
  - -qfloat, -qflttrap
- **Diagnostic options**
  - -qlist, -qreport, -qinitauto



Optimization Options

- **OPTIMIZE: specified as -qoptimize=n or -On where n is one of:**
  - **0**: Fast compilation, full support for debugging
  - **2**: Comprehensive low-level optimization, partial support for debugging (procedure boundaries)
  - **3**: Even more optimization - compile time/space intensive and/or marginal effectiveness
  - **4**: Macro option including -O3, -qhot, -qipa, -qarch=auto, -qtune=auto, -qcache=auto
  - **5**: Macro option including -O4, -qipa=level=2

Optimization Options (*continued*)

- **HOT (High Order Transformations) - Fortran (C and C++ coming soon)**
  - Specified as -qhot[=[no]vector | arraypad[=*n*]]
  - Optimized handling of F90 array language constructs (elimination of temporaries, fusion of statements)
  - High level transformation (eg. interchange) of loop nests to improve memory locality (reduce cache/TLB misses), optimize usage of hardware prefetch and balance loop computation (typically ld/st vs. float)
  - *Optionally* transforms loops to exploit vector intrinsic library (eg. reciprocal, sqrt, trig) - may result in slightly different rounding
  - *Optionally* introduces array padding under user control - potentially unsafe if not applied uniformly

Optimization Options (*continued*)

- **IPA (Inter-Procedural Analysis) - Fortran and C (C++ coming soon)**
  - Specified as -qipa[=level=*n* | inline= | *fine tuning*] on both compile *and* link steps
  - Expand the scope of optimization to an entire program unit (executable or shared object)
  - *level=0*: Program partitioning and simple interprocedural optimization
  - *level=1*: Inlining and global data mapping
  - *level=2*: Global alias analysis, specialization, interprocedural data flow
  - *inline=*: Precise user control of inlining
  - *fine tuning*: Specify library code behaviour, tune program partitioning, read commands from a file

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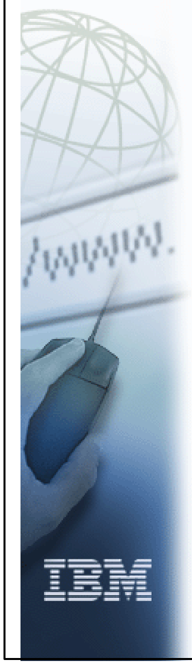

Target Machine Options

- **ARCH**
  - Restricts the compiler to generate a subset of the Power or PowerPC instruction set
  - Specified as -qarch=*isa* where *isa* is one of:
    - *com* (default): Code can run on any RS/6000 - implies -qtune=pwr2
    - *auto*: Code may take advantage of instructions available only on the compiling machine (or similar machines)
    - *ppc*: Code follows PowerPC architecture - implies -qtune=604 (32 bit) or -qtune=pwr3 (64 bit)
    - *pwr3*: Code can run on any Power 3 - implies -qtune=pwr3
    - Lots of others: *pwr, pwr2, 604, ...*

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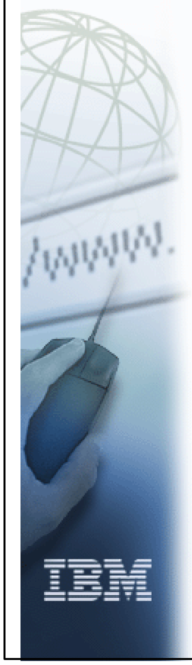


Target Machine Options *(continued)*

- **TUNE:** Bias optimization toward execution on a given machine
  - Does *not* imply anything about the ability to run correctly on a given machine - only affects performance
  - Specified as -qtune=*machine* where *machine* is one of auto, 604, pwr2, p2sc, pwr3, rs64a, etc.
- **CACHE**: Defines a specific cache/memory geometry
  - Defaults are set through TUNE
  - Specified as -qcache=level=*n*:*cache_spec*, where *cache_spec* includes:
    - type=i|d|c: cache type (instruction/data/combined)
    - line=*lsz*:size=*sz*:assoc=*as*: line/cache size and set associativity
    - cost=*c*: cost (in cpu cycles) of a miss

Target Machine Options *(continued)*

- **64/32**: Generate code for 64 bit (4/8/8) or 32 bit (4/4/4) addressing model
  - ► Specified as -q32 or -q64
- **SMP (Fortran, C)**: Generate threaded code for a shared-memory parallel machine
  - ► Specified as -qsmp[=[no]auto:=[no]omp:*fine tuning*]
  - ► *auto* instructs the compiler to automatically generate parallel code where possible without user assistance
  - ► *omp* instructs the compiler to observe OpenMP 1.0 language extensions for specifying explicit parallelism
  - ► *fine tuning* includes control over thread scheduling, nested parallelism and locking

Program Behaviour Options

- **STRICT**
  - ► Specified as -q[no]strict, default is -qstrict with -qoptimize=0 and -qoptimize=2, -qnostrict with -qoptimize=3,4,5
  - ► *nostrict* allows the compiler to reorder floating point calculations and potentially excepting instructions
- **ALIAS (Fortran)**
  - ► Specified as -qalias=[no]std:[no]aryovrlp:*others*
  - ► Allows the compiler to assume that certain variables do not refer to overlapping storage
  - ► *std* (default) refers to the rule about storage association of reference parameters with each other and globals
  - ► *aryovrlp* (default) defines whether there are any assignments between storage-associated arrays - try -qalias=noaryovrlp for better performance

Program Behaviour Options (*continued*)

- **ALIAS (C, C++)**
  - Similar to Fortran option of the same name but focussed on overlap of storage accessed using pointers
  - Specified as -qalias=*subopt* where *subopt* is one of:
    - *[no]ansi*: Enable ANSI standard type-based alias rules
    - *[no]typeptr*: Assume pointers to different types never point to the same or overlapping storage
    - *[no]allptrs*: Assume that different pointer variables always point to non-overlapping storage
    - *[no]addrtaken*: Assume that external variables do not have their address taken outside the source file being compiled

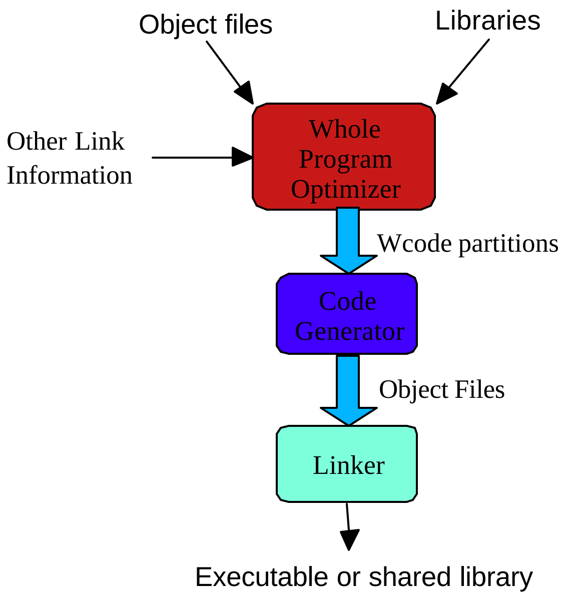
Directives and Pragmas

- **OpenMP 1.0** - supported in C and Fortran
- **Legacy SMP** directives and pragmas
  - Most of these are superceded by OpenMP - use OpenMP where possible
- **Assertive directives** (Fortran)
  - ASSERT, INDEPENDENT, CNCALL, PERMUTATION
- **Assertive pragmas** (C)
  - *isolated_call*, *disjoint, independent_loop, independent_calls, iterations, permutation, execution_frequency, leaves*
- **Embedded Options**
  - *#pragma options* and *#pragma option_override* in C
  - @PROCESS in Fortran
- **Prescriptive directives** (Fortran)
  - PREFETCH, UNROLL
- **Prescriptive pragmas** (C)
  - *sequential_loop*

Diagnostic Options

- **LIST**
  - Specified as -qlist
  - Instructs the compiler to emit an object listing
  - The object listing includes hex and pseudo-assembly representations of the generated code along with traceback tables and text constants
- **REPORT (Fortran)**
  - Specified as -qreport [=smplist]
  - Instructs the high level optimizer to emit a report including pseudo-Fortran along with annotations describing what transformations were performed (eg. loop unrolling, automatic parallelization)
  - Also includes information about data dependences and other inhibitors to optimization

Inside an Link-time Compilation



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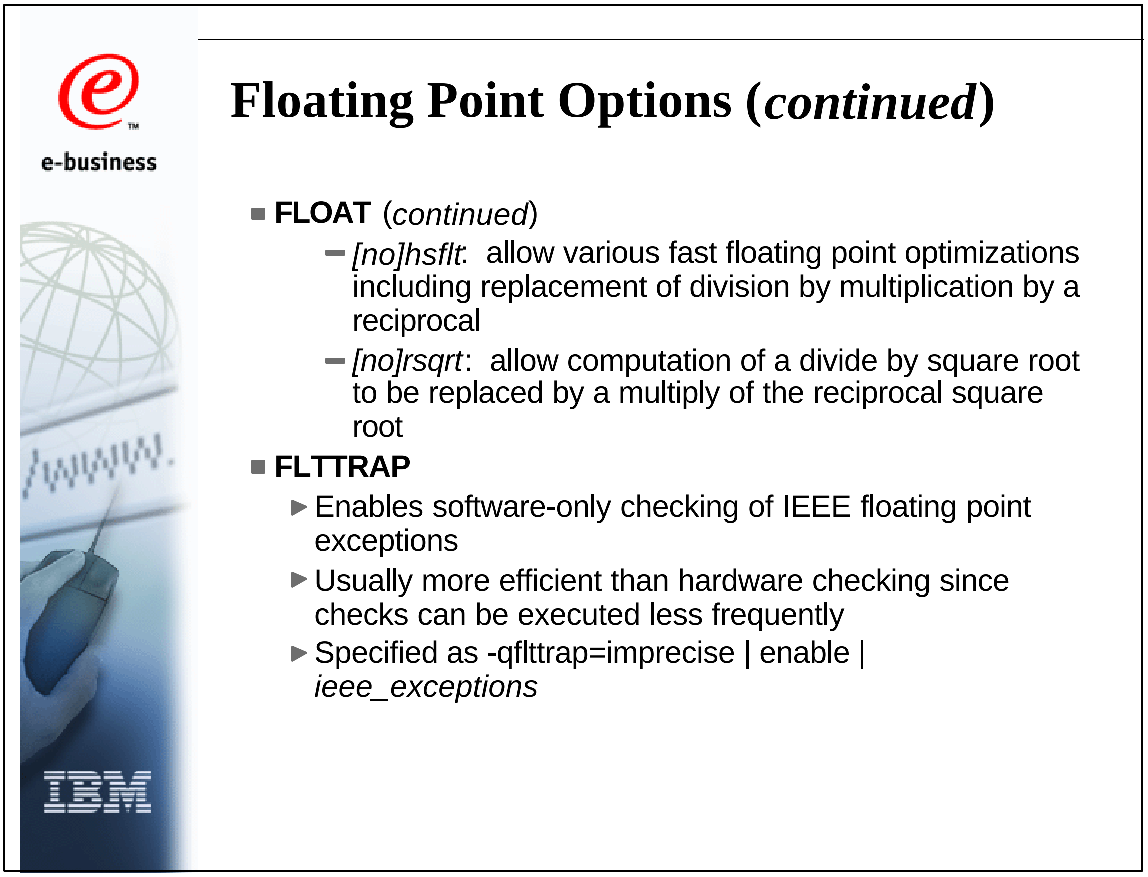
Backup

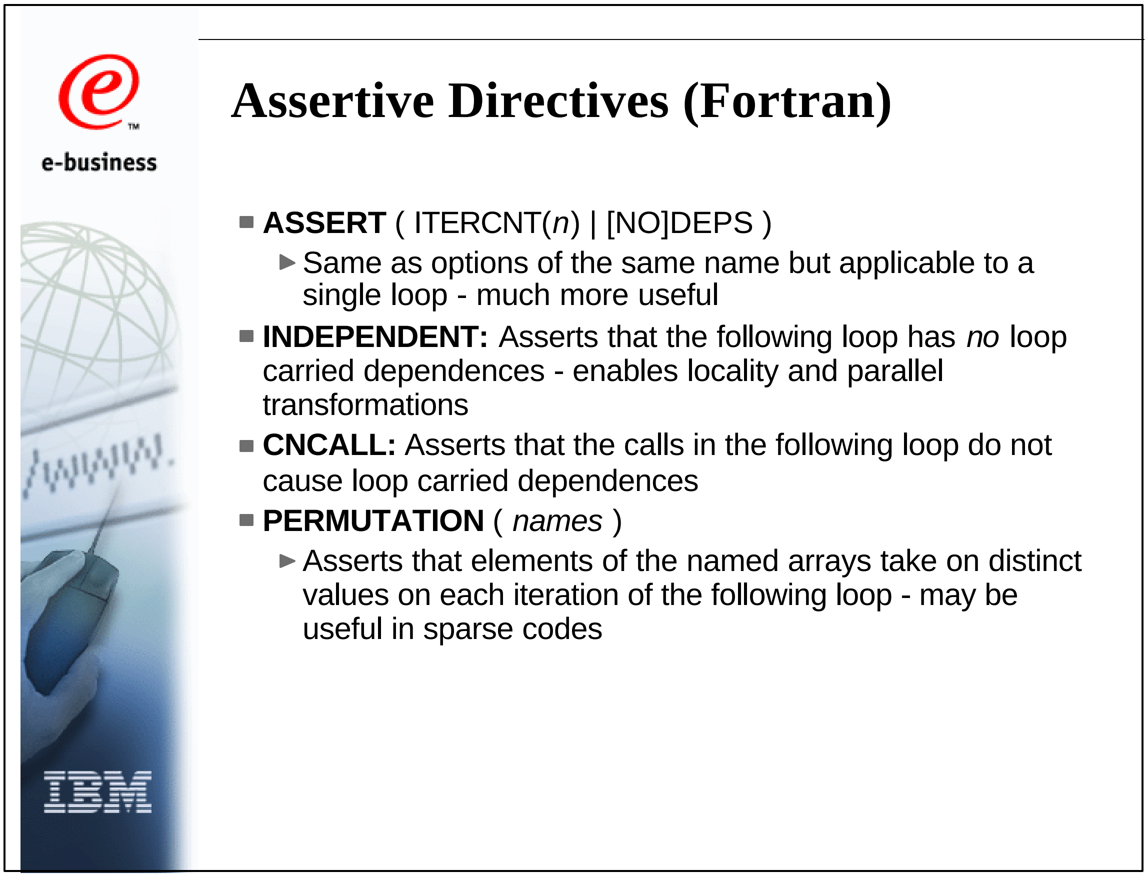
Floating Point Options

- **FLOAT**
  - Precise control over the handling of floating point calculations
  - Specified as -qfloat=*subopt* where *subopt* is one of:
    - *[no]fold*: enable compile time evaluation of floating point calculations - may want to disable for handling of certain exceptions (eg. overflow, imprecise)
    - *[no]maf*: enable generation of multiple-add type instructions - may want to disable for exact compatibility with other machines but this will come at a high price in performance
    - *[no]rrm*: specifies that rounding mode may not be round-to-nearest (default is *norrm*)



Floating Point Options (*continued*)

- **FLOAT** (*continued*)
  - *[no]hsflt*: allow various fast floating point optimizations including replacement of division by multiplication by a reciprocal
  - *[no]rsqrt*: allow computation of a divide by square root to be replaced by a multiply of the reciprocal square root
- **FLTTRAP**
  - Enables software-only checking of IEEE floating point exceptions
  - Usually more efficient than hardware checking since checks can be executed less frequently
  - Specified as -qflttrap=imprecise | enable | *ieee_exceptions*



Assertive Directives (Fortran)

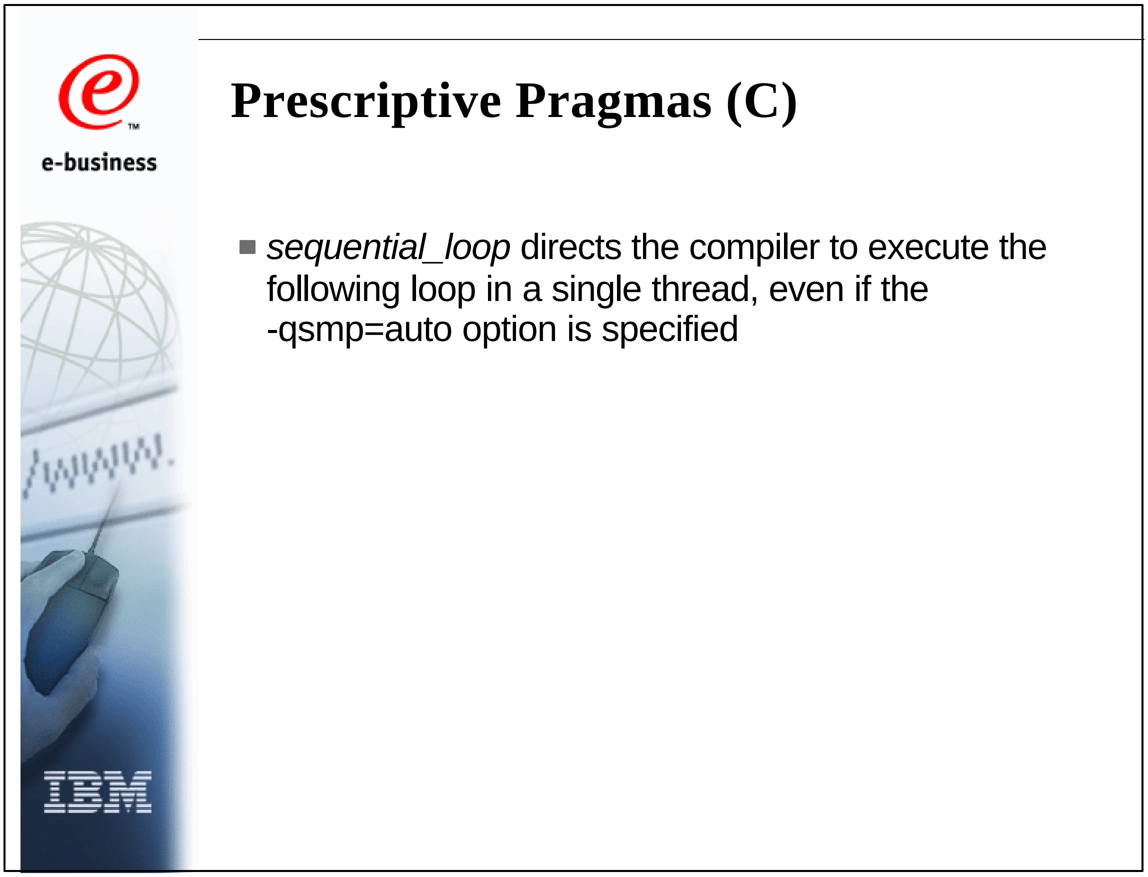
- **ASSERT** (ITERCNT(*n*) | [NO]DEPS)
  - Same as options of the same name but applicable to a single loop - much more useful
- **INDEPENDENT:** Asserts that the following loop has *no* loop carried dependences - enables locality and parallel transformations
- **CNCALL:** Asserts that the calls in the following loop do not cause loop carried dependences
- **PERMUTATION** (*names*)
  - Asserts that elements of the named arrays take on distinct values on each iteration of the following loop - may be useful in sparse codes

Assertive Pragmas (C)

- *isolated_call* (*function_list*) asserts that calls to the named functions do not have side effects
- *disjoint* (*variable_list*) asserts that none of the named variables share overlapping areas of storage
- *independent_loop* is equivalent to INDEPENDENT
- *independent_calls* is equivalent to CNCALL
- *permutation* is equivalent to PERMUTATION
- *iterations* is equivalent to ASSERT(ITERCNT)
- *execution_frequency* (*very_low*) asserts that the control path containing the pragma will be infrequently executed
- *leaves* (*function_list*) asserts that calls to the named functions will not return (eg. exit)

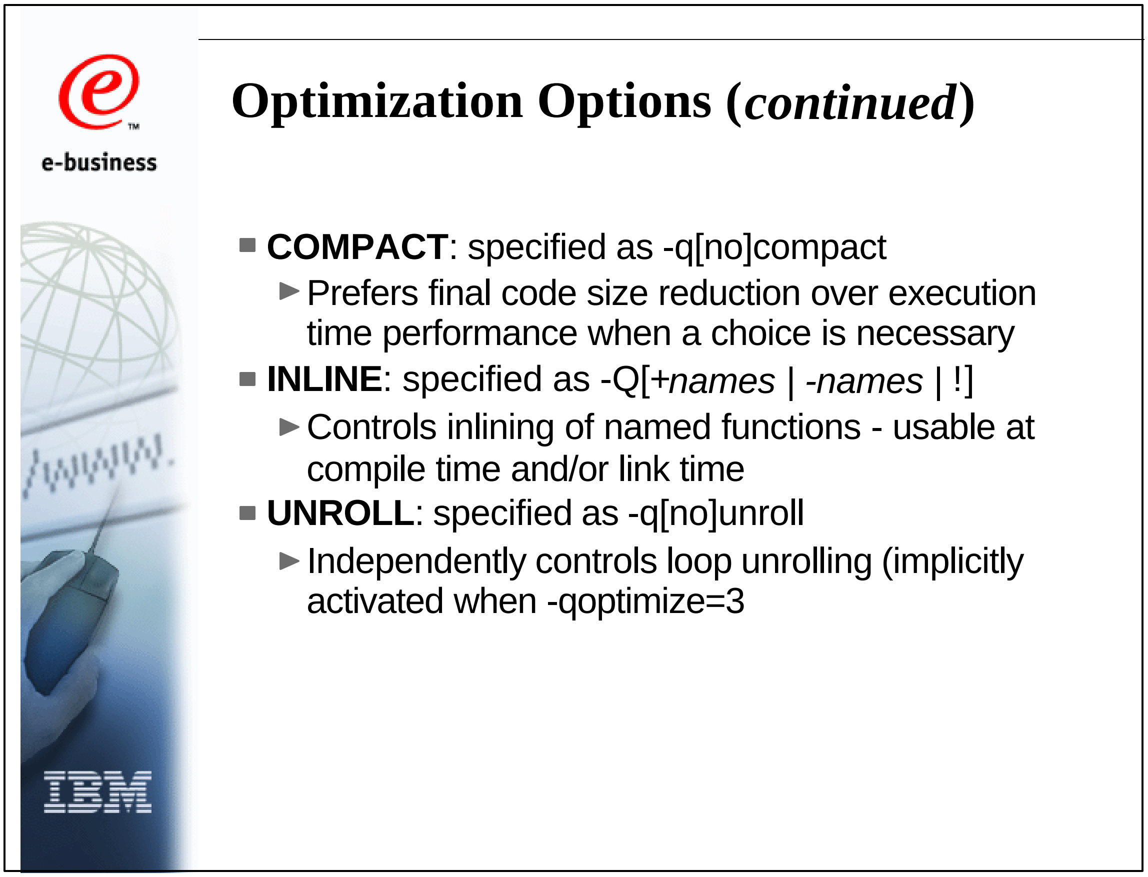
Prescriptive Directives (Fortran)

- **PREFETCH**
  - PREFETCH_BY_LOAD (*variable_list*): issue *dummy* loads to cause the given variables to be prefetched into cache - useful on Power machines or to activate Power 3 hardware prefetch
  - PREFETCH_FOR_LOAD (*variable_list*): issue a *dcbt* instruction for each of the given variables.
  - PREFETCH_FOR_STORE (*variable_list*): issue a *dcbtst* instruction for each of the given variables.
- **UNROLL**
  - Specified as [NO]UNROLL [(*n*)]
  - Used to activate/deactivate compiler unrolling for the following loop.
  - Can be used to give a specific unroll factor.



Prescriptive Pragmas (C)

- *sequential_loop* directs the compiler to execute the following loop in a single thread, even if the -qsmp=auto option is specified



Optimization Options (*continued*)

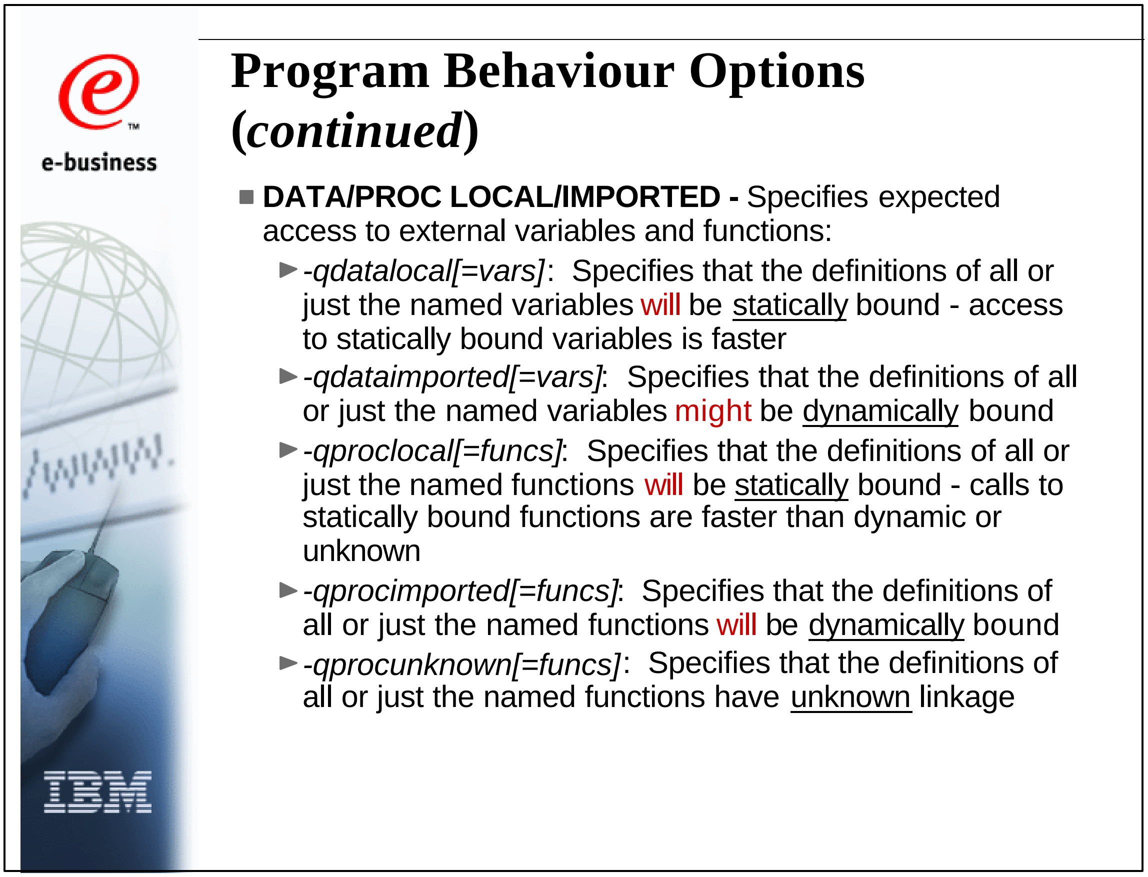
- **COMPACT**: specified as -q[no]compact
  - Prefers final code size reduction over execution time performance when a choice is necessary
- **INLINE**: specified as -Q[+*names* | -*names* | !]
  - Controls inlining of named functions - usable at compile time and/or link time
- **UNROLL**: specified as -q[no]unroll
  - Independently controls loop unrolling (implicitly activated when -qoptimize=3

Optimization Options (*continued*)

- **INLGLUE** - Specified as *-q[no]inlglue*
  - Inline calls to "glue" code used in calls through function pointers (including *virtual*) and calls to functions which are dynamically bound
- **TBTABLE**
  - Controls the generation of traceback table information:
  - *-qtbtable=none* inhibits generation of tables - no stack unwinding is possible
  - *-qtbtable=small* generates tables which allow stack unwinding but omit name and parameter information - useful for optimized C++
  - *-qtbtable=full* generates full tables including name and parameter information - useful for debugging

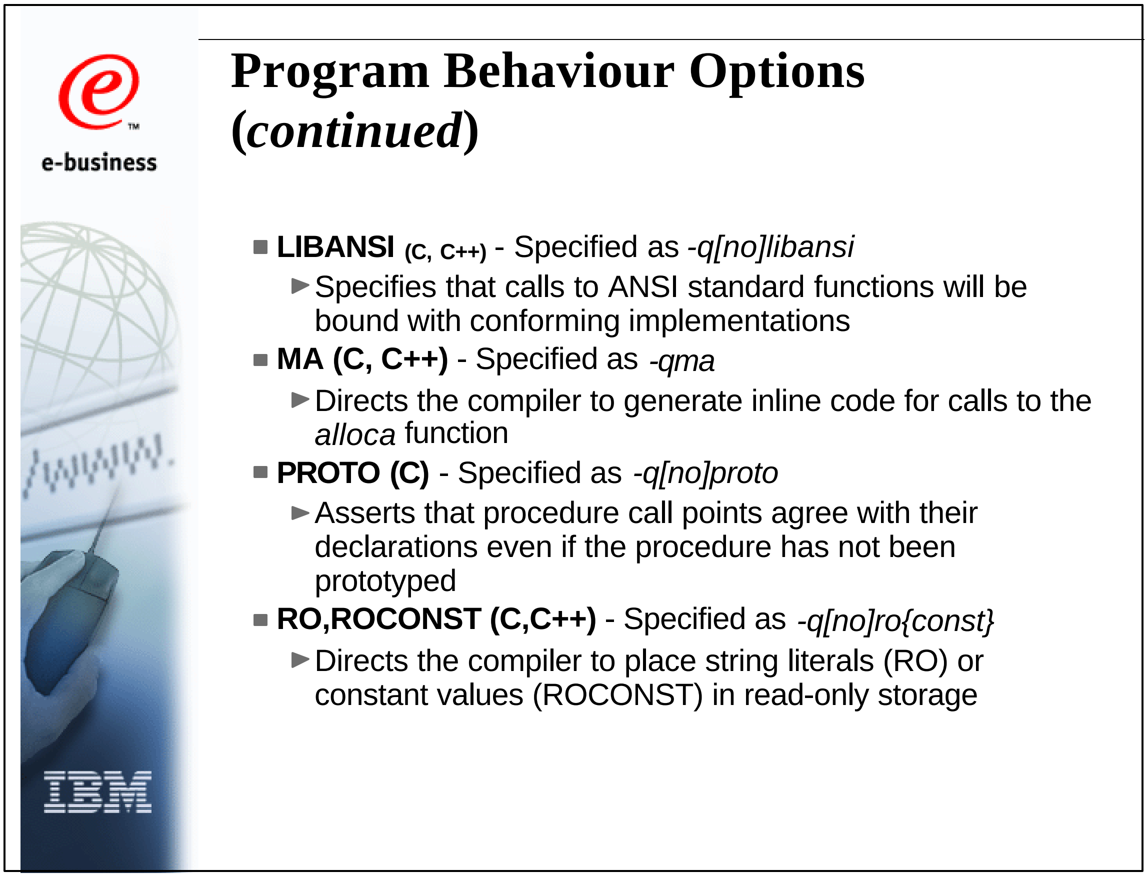
Program Behaviour Options (*continued*)

- **ASSERT (Fortran, C)**
  - Specified as -qassert=[no]deps | itercnt=*n*
  - *deps* (default) indicates that some loop has a loop carried memory dependence - try -qassert=nodeps for improved performance
  - *itercnt* modifies the default assumptions about the expected iteration count of loops (normally 10)
- **INTSIZE (Fortran)**: Define the default size of INTEGER variables
  - Specified as -qintsize=1|2|4|8
  - When using -q64, try -qintsize=8 for improved performance
- **IGNERRNO (C,C++)** - Specified as *-q[no]ignerrno*
  - Indicates that the value of *errno* is not needed by the program



Program Behaviour Options (*continued*)

- **DATA/PROC LOCAL/IMPORTED -** Specifies expected access to external variables and functions:
  - ► *-qdatalocal[=vars]*: Specifies that the definitions of all or just the named variables will be statically bound - access to statically bound variables is faster
  - ► *-qdataimported[=vars]*: Specifies that the definitions of all or just the named variables might be dynamically bound
  - ► *-qproclocal[=funcs]*: Specifies that the definitions of all or just the named functions will be statically bound - calls to statically bound functions are faster than dynamic or unknown
  - ► *-qprocimported[=funcs]*: Specifies that the definitions of all or just the named functions will be dynamically bound
  - ► *-qprocunknown[=funcs]*: Specifies that the definitions of all or just the named functions have unknown linkage



Program Behaviour Options (*continued*)

- **LIBANSI** **(C, C++)** - Specified as *-q[no]libansi*
  - ► Specifies that calls to ANSI standard functions will be bound with conforming implementations
- **MA (C, C++)** - Specified as *-qma*
  - ► Directs the compiler to generate inline code for calls to the *alloca* function
- **PROTO (C)** - Specified as *-q[no]proto*
  - ► Asserts that procedure call points agree with their declarations even if the procedure has not been prototyped
- **RO,ROCONST (C,C++)** - Specified as *-q[no]ro{const}*
  - ► Directs the compiler to place string literals (RO) or constant values (ROCONST) in read-only storage